

# APPARENT EQUILIBRIUM BETWEEN PHOTOSYNTHESIS AND RESPIRATION IN AN UNRENEWED ATMOSPHERE

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(WITH FIVE FIGURES)

Under full sunlight intensity, the rate of photosynthesis is usually about 3 to 10 times as great as the rate of respiration; and it would be expected that if the external supply of carbon dioxide were cut off entirely, the apparent equilibrium between the two processes at high light intensity would be established at a rather low concentration of carbon dioxide. No quantitative information seems to be available in the literature on this subject, at least so far as the higher plants, growing under natural conditions, are concerned. This paper describes experiments that were carried out with grain, alfalfa, and sugar beets, to study the equilibrium concentration of carbon dioxide at high light intensity in an unrenewed atmosphere.

## Method

The portable celluloid plant chamber (3) and also the sand culture equipment (2) were used in this study. A blower was mounted between the outlet and intake pipes of the plant chamber in order to recirculate the air over the plants. Care was taken to stop all leaks in the system by the use of case-mastic. Pressure differentials from the outside which might cause leaks were mainly near the blower; the pressure in the plant chamber was only slightly different from that outside. During the latter part of the experiment with sugar beets, a small fan was mounted in the cabinet to produce mixing, and the external blower was eliminated. This latter arrangement was more convenient, and probably reduced leakage slightly. Carbon dioxide analyses were made continuously in the circulating air stream by means of the autometer (3). Temperature and light intensity measurements were also made continuously.

A plot of mixed spring wheat, barley, and winter wheat in sand culture (2) was studied between June 30 and July 4, 1942. The spring wheat and barley were in the milk stage and the plants were still green. The winter wheat was entirely vegetative. Total top growth as estimated from harvest data taken a month later was equivalent to about 2400 gm. of dry weight. The alfalfa was young fourth crop, 12 to 15 inches high, growing in soil. It was studied September 30, 1943, using the celluloid plant chamber (3). There were 380 gm. of leaves and 555 gm. of stems (dry weight) on the plot. The sugar beets were large plants growing in sand culture (2). The experiments were performed on November 3-4, 1943. The dry harvest weight of the tops (November 5) was 2330 gm. of which 1190 gm. were leaf blades and 1140 gm. petioles. During the measurements in the sand cultures, a very

slow stream of air was drawn down through the sand to prevent carbon dioxide produced by the respiration of the roots from diffusing upward into the air surrounding the tops.

### Results

In the first experiment with grain, the carbon dioxide concentration fell rapidly to 180 p.p.m., then increased during the following hour to 320 p.p.m. The air temperature of the plant chamber increased during this period from

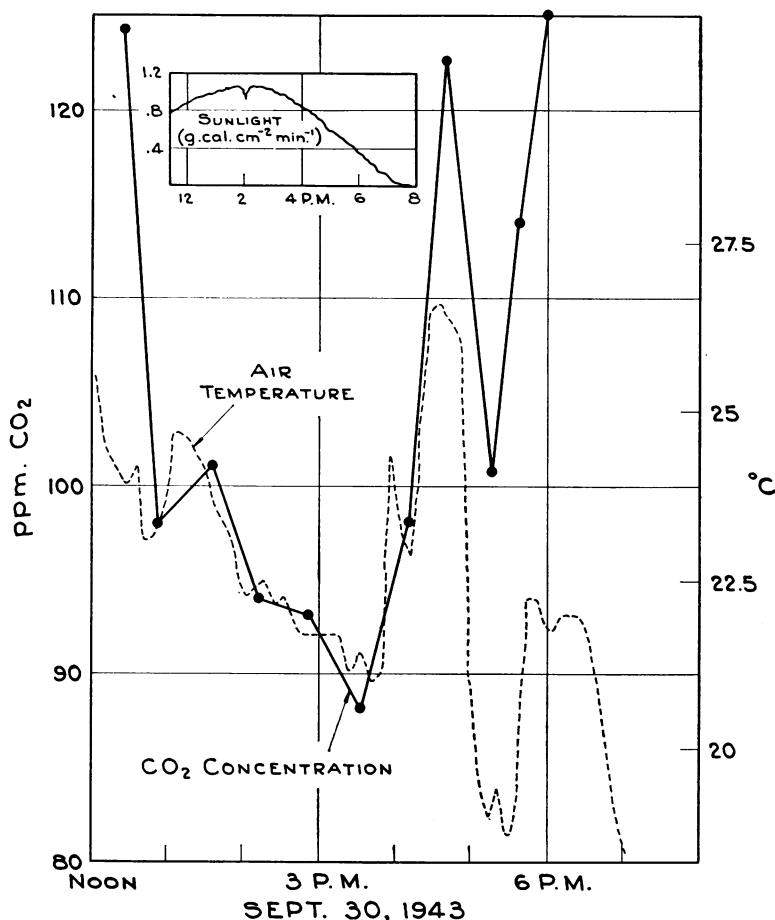


FIG. 1. Apparent carbon dioxide equilibrium in an unrenewed atmosphere between photosynthesis and respiration of alfalfa growing in the field, at different air temperatures and sunlight intensities.

28° to 42° C. The next day the experiment was repeated, using a spray of water on the pipes and glass to control the temperature. The carbon dioxide concentration again fell rapidly, reaching a minimum value of 88 p.p.m. at 24.5°. In a third experiment 76 p.p.m. was reached at 23°.

The results of the alfalfa experiment are presented in figure 1 in which carbon dioxide concentration and the air temperatures are plotted against

the time of day (mountain war time). A copy of a pyrliometer record is also included, to show insolation on a horizontal surface. When apparent equilibrium was established, the carbon dioxide and temperature followed each other very closely until the late afternoon when the light intensity fell off and reduced photosynthesis, permitting the carbon dioxide to rise. A minimum carbon dioxide concentration of 88 p.p.m. was reached at 21° C. This is an appreciably higher minimum than with the grain. The higher concentration may be due in part to carbon dioxide from the soil which, though small, is measurable. It is likely also that there was some leakage since the celluloid cabinets are not entirely gas tight.

The sugar beet experiment was carried out on November 3rd and 4th when the outside temperature was low. The experiment was started using

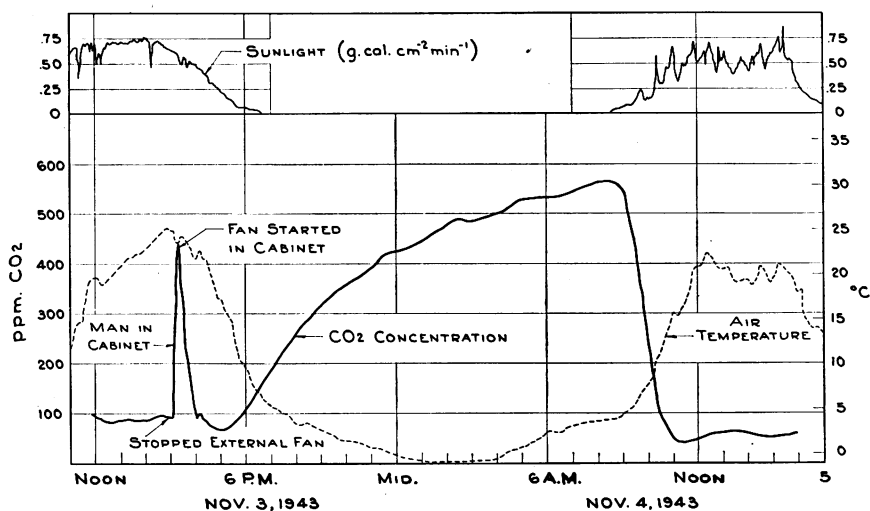


FIG. 2. Apparent carbon dioxide equilibrium, in an unrenewed atmosphere, between photosynthesis and respiration of sugar beets growing in sand culture, as influenced by different air temperatures and sunlight intensities.

the outside blower but at 3 P.M. November 3, a man entered the plant chamber (fig. 2) for about 10 minutes to mount a small fan and place two sampling tubes, one near the surface of the plants, and the other near the top of the chamber. The intake and outlet pipes were then tightly blocked. Good mixing was accomplished by the small fan as indicated by the concordance of the carbon dioxide analyses at the two sampling points. Leakage was evidently slight, and probably did not exceed appreciably, the small air stream (10 liters per minute) which was drawn down into the sand to remove carbon dioxide produced by the roots.

Figure 2 gives a summary of the carbon dioxide concentrations over a period of 28 hours. The graph includes the air temperature and the sunlight intensity. During the day there was marked lowering of the carbon dioxide concentration which normally is about 310 p.p.m. This is well

illustrated by the short period when a man entered the cabinet and the concentration went up suddenly from 90 p.p.m. to 430 p.p.m., then went down again during a 40-minute period to its original value. On a number of occasions it has been noted that the respiration of a man entering the cabinet is several fold the photosynthetic absorption in one of these six-foot square cabinets well filled with vegetation.

During the night, the carbon dioxide level rose to 560 p.p.m. in spite of

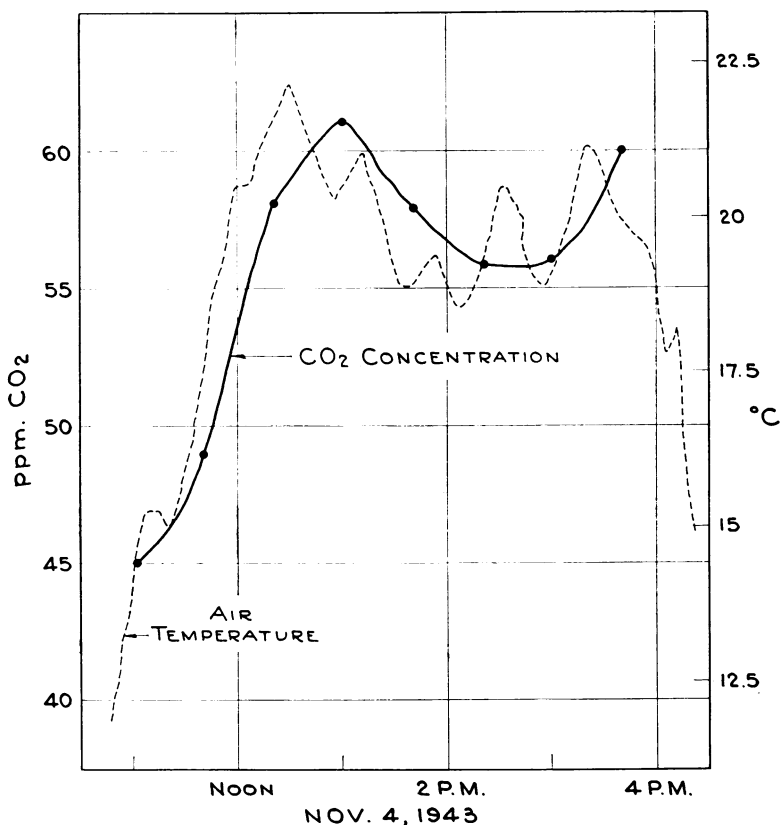


FIG. 3. Apparent equilibrium between photosynthesis and respiration (40-minute periods) at different air temperatures, of the sugar beets represented in figure 2.

the low temperature prevailing. The slight rise of temperature during the early hours of the morning seemed to be accompanied by a corresponding rise in the carbon dioxide level. With the coming of sunlight, the level fell over a two-hour period to about 40 p.p.m., then rose a little as the temperature increased.

Figure 3 shows the temperature and carbon dioxide curves for sugar beets on November 4, plotted on comparable scales. The dependence of the carbon dioxide level on temperature is as striking for sugar beets as for alfalfa (fig. 1).

The carbon dioxide data in figures 1 and 3 and most of the data in figure 2, represent average concentration over 40-minute periods. The analytical values, however, can be read from the record at 2.5- or 5-minute intervals if desired, though obviously the values so determined will be less accurate than 40-minute averages. Since November 4 was a day of intermittent sunshine with approximately constant average hourly illumination from about 11 A.M. to 4 P.M. it seemed desirable to determine if the short period fluctuations of the light intensity caused similar short period fluctuations of the carbon dioxide level. It would, of course, be expected that high light intensity would decrease the carbon dioxide level and *vice versa*.

Figure 4 gives the detailed fluctuations of these variables, using 5-minute

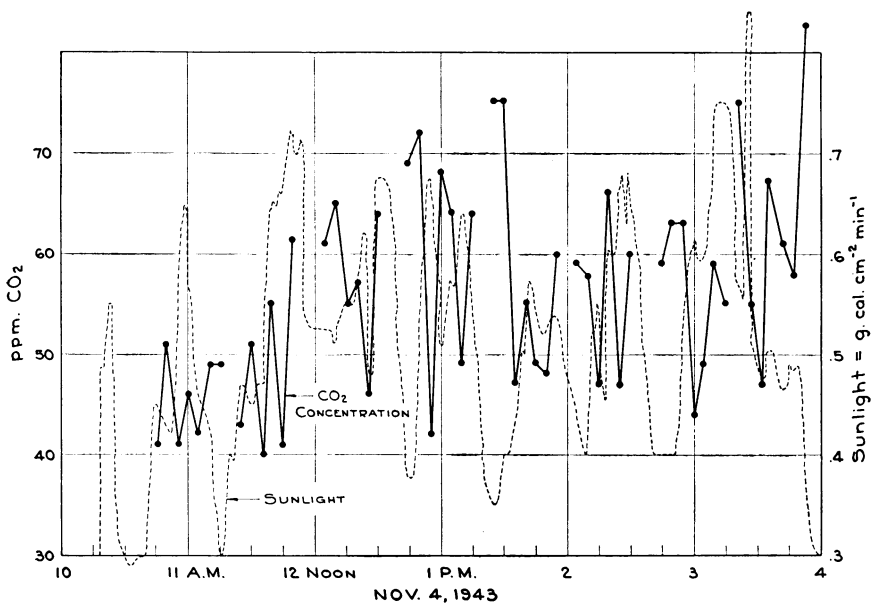


FIG. 4. Short period (5-minute) variations of the apparent equilibrium between photosynthesis and respiration with variable light intensity on a partly cloudy day, of the sugar beets represented in figures 2 and 3.

averages for the carbon dioxide. The omission of one carbon dioxide value in each 40-minute period is due to an operating characteristic of the analyzer which employs one 5-minute period in each 40 minutes for a zero adjustment. In nearly all cases the values of light and carbon dioxide changed in opposite directions. The only obvious exceptions occurred at 11:50 A.M. and 2:30 P.M. and were probably analytical errors. Evidently a definite balance was established in this plot between respiration and photosynthesis, which was shifted rapidly as the light intensity changed.

### Discussion

Figure 5 summarizes all of the values of carbon dioxide at different temperatures when apparent equilibrium had been established. The curve for

the grain appears to be linear with a temperature coefficient ( $Q_{10}$ ) of 2.0. The data for sugar beets seem to be a continuation of the grain curve but with a smaller temperature gradient. Data at higher temperatures for sugar beets and at lower temperatures for grain would be useful. Some of the points for sugar beets are displaced to the right. These values were all obtained on November 3, before the outside circulating blower was discontinued. Probably there was some leakage in the blower system. The data for alfalfa are also displaced to the right, indicating either a higher respiration-photosynthesis ratio or, more likely, the influence of carbon dioxide derived from the soil, as well as some leakage in the blower.

From an inspection of the assimilation and respiration record of the

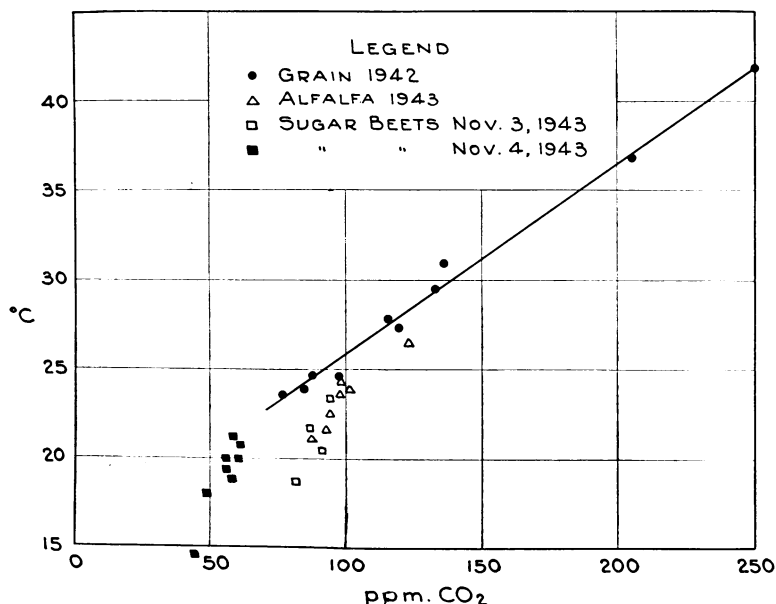


FIG. 5. Average carbon dioxide concentration of an unrenewed atmosphere at different temperatures after apparent equilibrium between photosynthesis and respiration had been reached in plots of grain, alfalfa, and sugar beets.

grain plot within a few days of July 1, 1942, it appears that the apparent assimilation was approximately 3 times the night respiration at 24°. The latter was found by extrapolating a series of values at lower temperatures. Allowing for respiration during the measurement of apparent assimilation, the level of photosynthesis was about 4 times the respiration level. It has been found that when the air was enriched with carbon dioxide, apparent assimilation increased proportionately to the carbon dioxide concentration. If a similar relationship holds at reduced concentrations, photosynthesis that was 4 times respiration at 300 p.p.m. carbon dioxide, would be equal to respiration at 75 p.p.m. A concentration of 76 p.p.m. was observed at 23° C. and 88 p.p.m. at 24.5° in the grain plot.

A similar calculation for alfalfa at 21° requires an equilibrium concentration of about 45 p.p.m. A minimum value of 88 p.p.m. was actually observed. This discrepancy further bears out the suspicion expressed earlier that a true equilibrium was not obtained between respiration and photosynthesis in the alfalfa-experiment.

In the sugar beets the ratio of photosynthesis to respiration was about 10 to 1 at 15° C. indicating a limiting concentration of about 30 p.p.m. carbon dioxide as compared with a minimum of 40 p.p.m. observed (fig. 4). This difference is probably not much greater than the uncertainty in the data, considering the preliminary nature of the experiments.

The investigation is being continued. It is evident that this method can supply useful information regarding respiration and photosynthesis. Particularly, the method may be useful in determining the rate of respiration of illuminated plants. The relationships so far found are in general agreement with the discussion of the "compensation point" by SPOEHR (1, pp. 176-179) so far as that discussion is applicable to the present study.

### Summary

The minimum concentration of carbon dioxide, to which an unrenewed atmosphere could be reduced by photosynthesis, was sought. A value of 40 p.p.m. was found for sugar beets at 15° C. The apparent equilibrium between photosynthesis and respiration was dependent on the temperature and the light intensity. In grain and sugar beet experiments the minimum equilibrium concentration agreed satisfactorily with values calculated from independent respiration and photosynthesis data. The method should be useful for fundamental studies in this field.

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